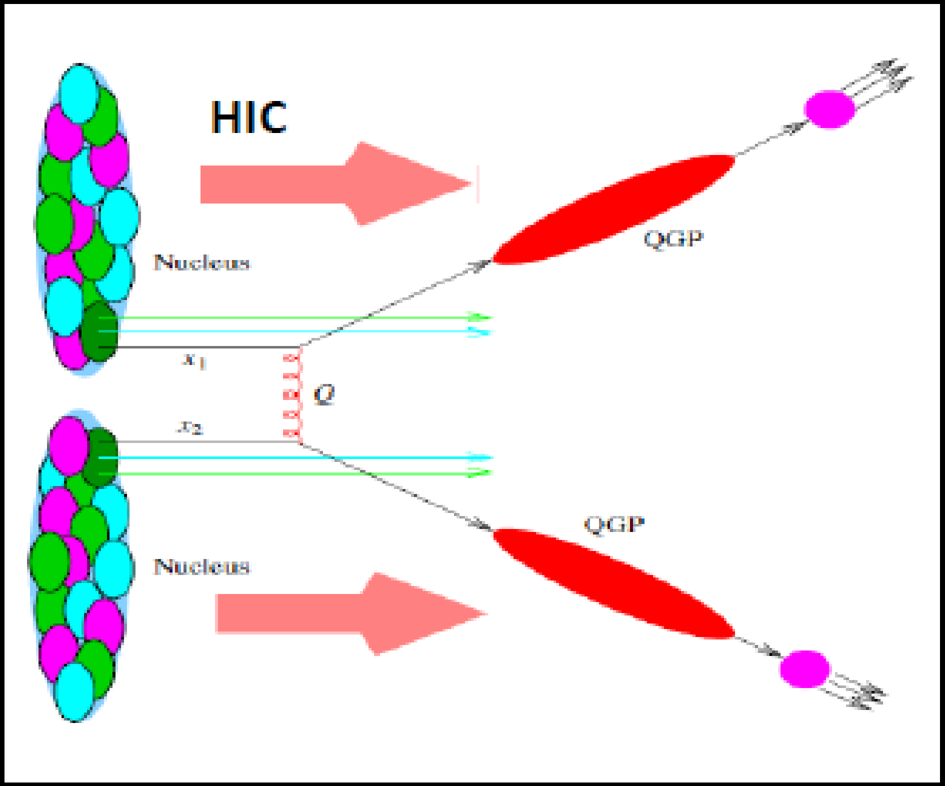
Jet physics with ALICE

Leticia Cunqueiro
INFN FRASCATI

For the ALICE Collaboration

DIS 2011 Newport News, April 2011

Jets in Heavy Ion Collisions



The scattered hard parton is produced early in time (t~1/sqrt(Q)).

It encounters the hot-dense medium through its evolution.

The medium is expected to modifiy its radiation pattern with respect to QCD by (dominantly at high jet energy) inducing the radiation of soft gluons leading to the well known phenomena of Jet Quenching.

Hadronization in vacuum for sufficiently boosted partons.

The picture is complicated compared to p+p:

--Nuclear effects in the PDFs

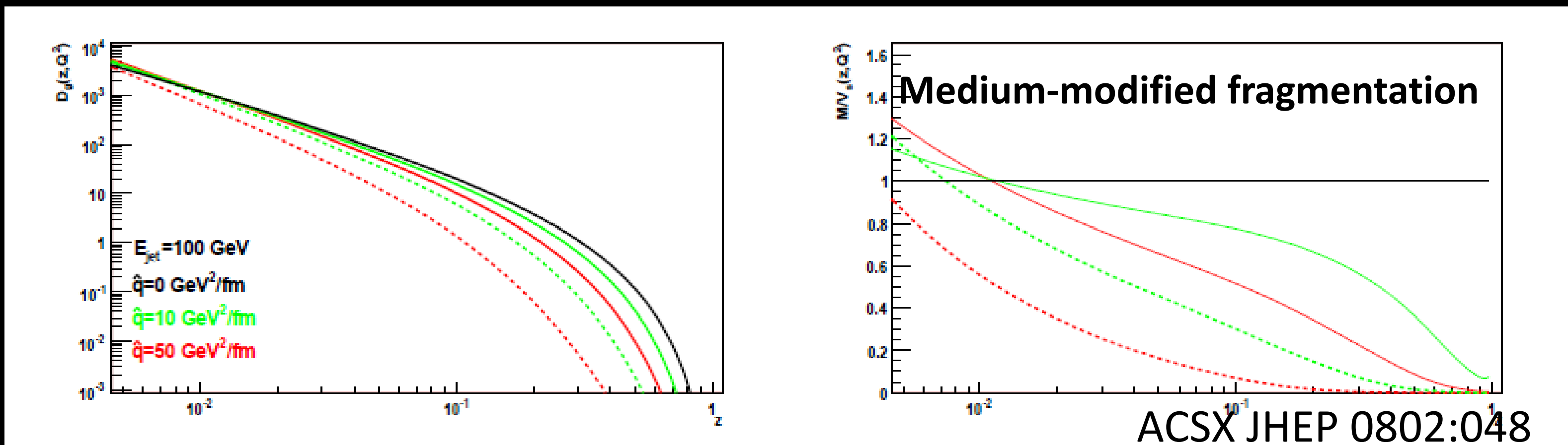
--Large Underlying event: ISR,multiple parton interactions,semihard collisions, beam-beam remnants… (we deal with ~1600 particles per unit rapidity @ 2.76 TeV)

--Other physical processes that may modifiy the jet: elastic energy loss,recombination, interplay between hadronization&medium, collective effects like elliptic flow….

Jet Quenching& full jet reconstruction

The medium changes the QCD jet radiation pattern via the induced emission of soft gluons. We expect:

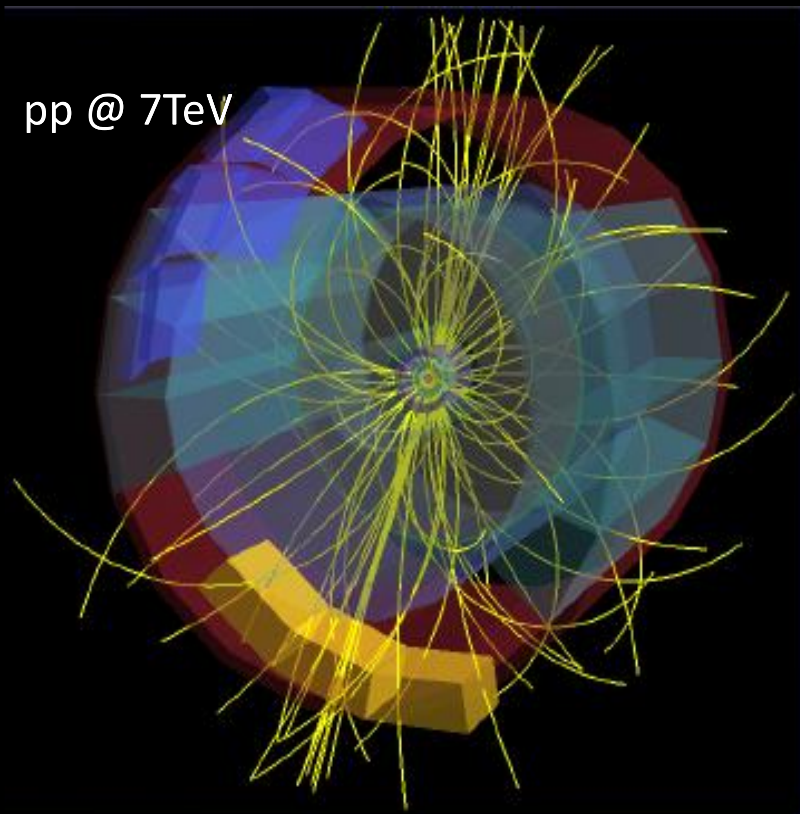
-degradation of the leading parton
-increase in the jet shower multiplicity
-average gain of momentum or "heating" of the intrajet pT

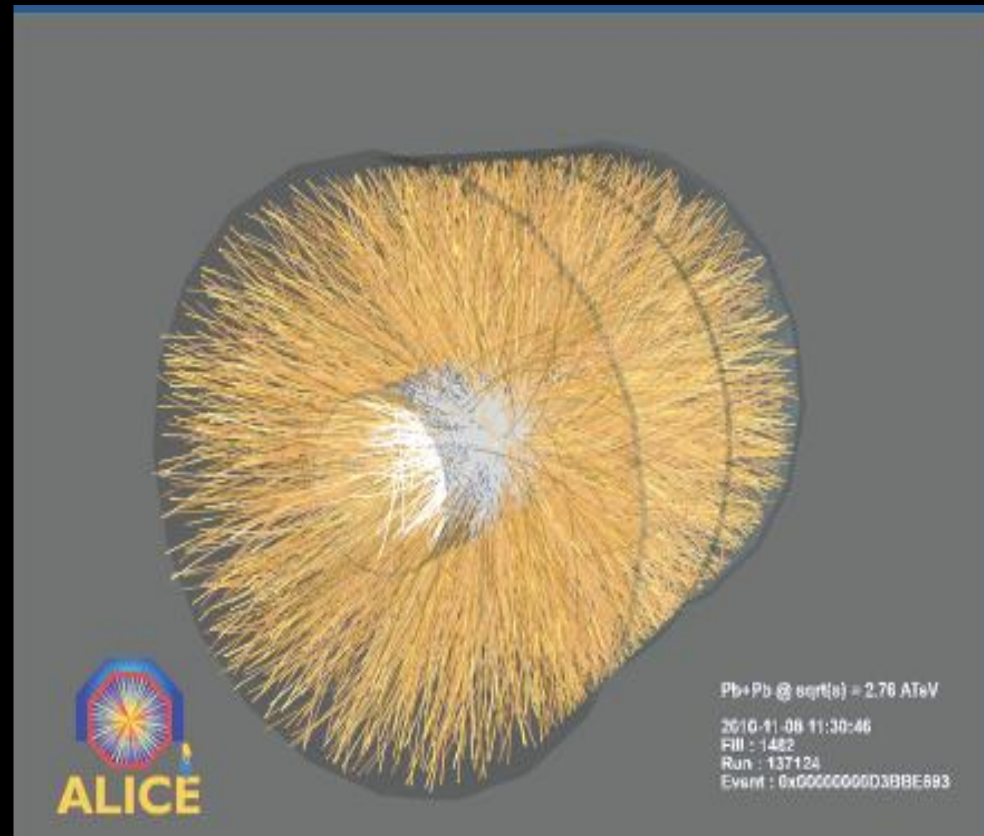


From the study of the energy redistribution inside **jets we aim extracting information like transport properties of the medium**: (i.e, in BDMPS formalism broadening and energy loss can be dynamically related via a single parameter, the qhat, which represents the average momentum given by the medium to the scattered parton per unit path length, thus linked to medium density)

But to fully capture the dynamics of the jet quenching we need full jet reconstruction.

Jet physics with ALICE





And full jet reconstruction is a challenge in HIC

Jet Physics with ALICE

1st year based on central tracking detectors

→jets from charged particles only

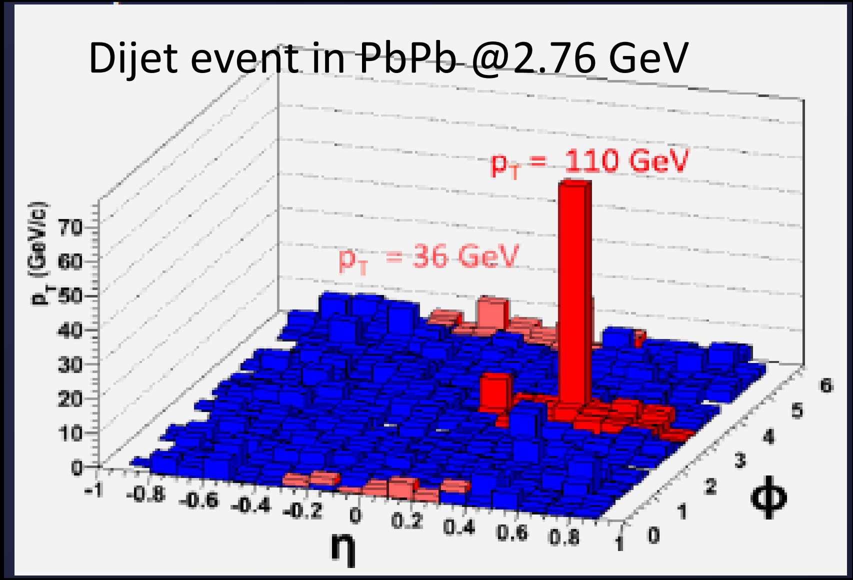
→low momentum cut off (150 MeV)
→good momentum resolution down to very low pT

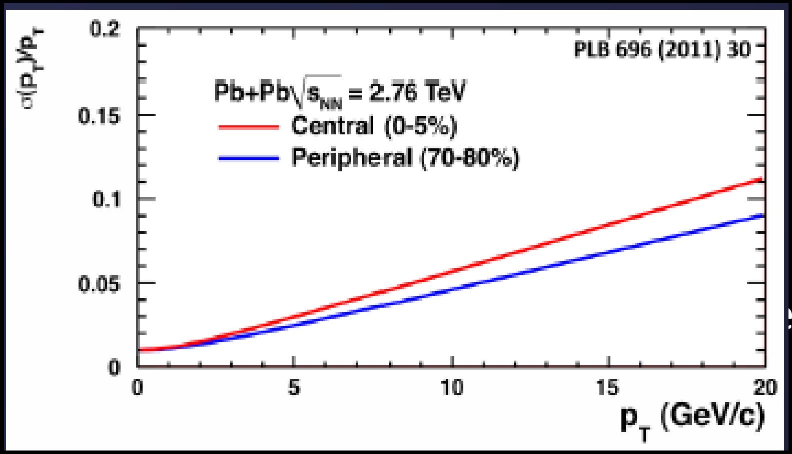
→clustering directly on particles, not on calorimeter cells

1.recover the whole jet structure.

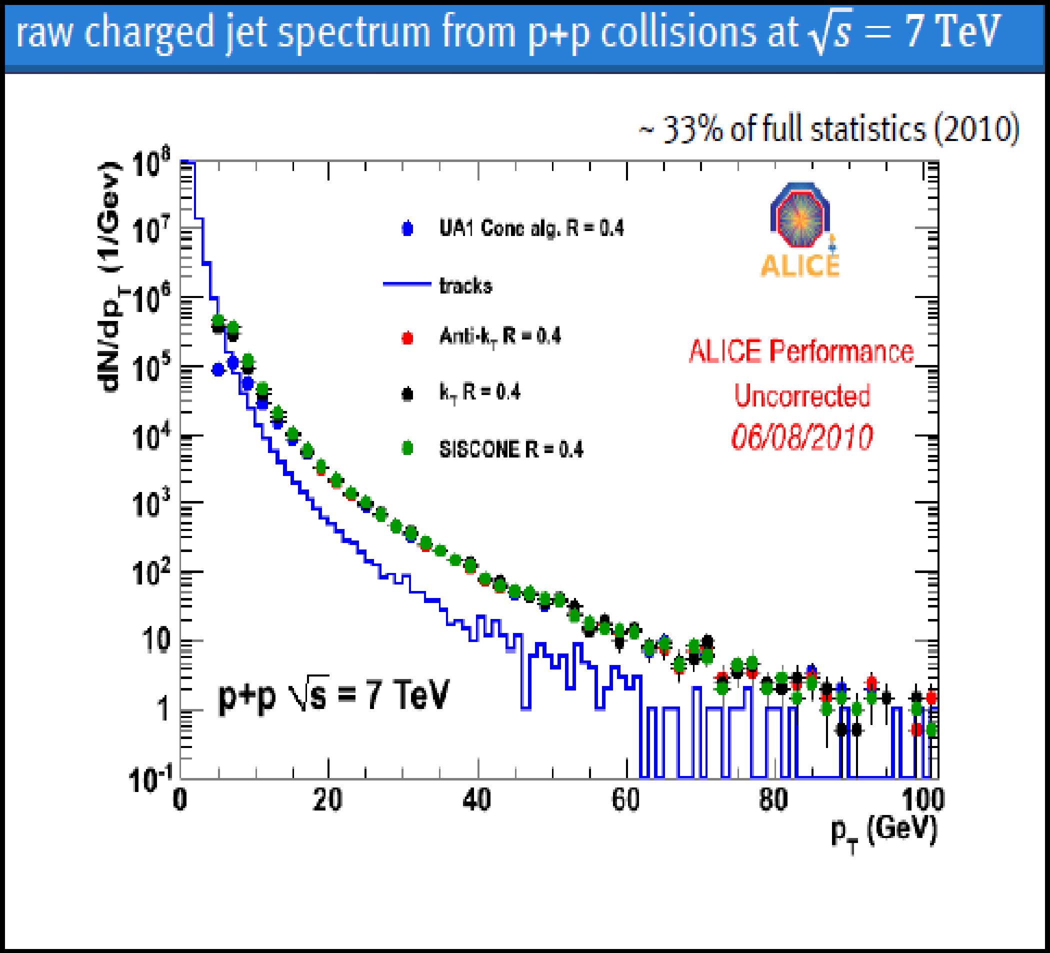
2.reduced bias towards hard fragmenting/unquenched jets.

3. But higher background





Jets in pp



Jets in pp or in peripheral PbPb collisions are the reference for the study of medium modifications.

-The UE is small→clean sample of jets, this allows to understand:

- **-detector response**
- **-jet finding characterisics**
- **-other uncertanties and systematics**

Good agreement between jet finders above 20 GeV.

Jets in PbPb: the background

$$p_{T,jet} = p_{T,jet}^{rec} - \rho \times A_{jet} \pm \sigma \times \sqrt{A_{jet}}$$

A_{jet} : jet area
σ: background fluctuations

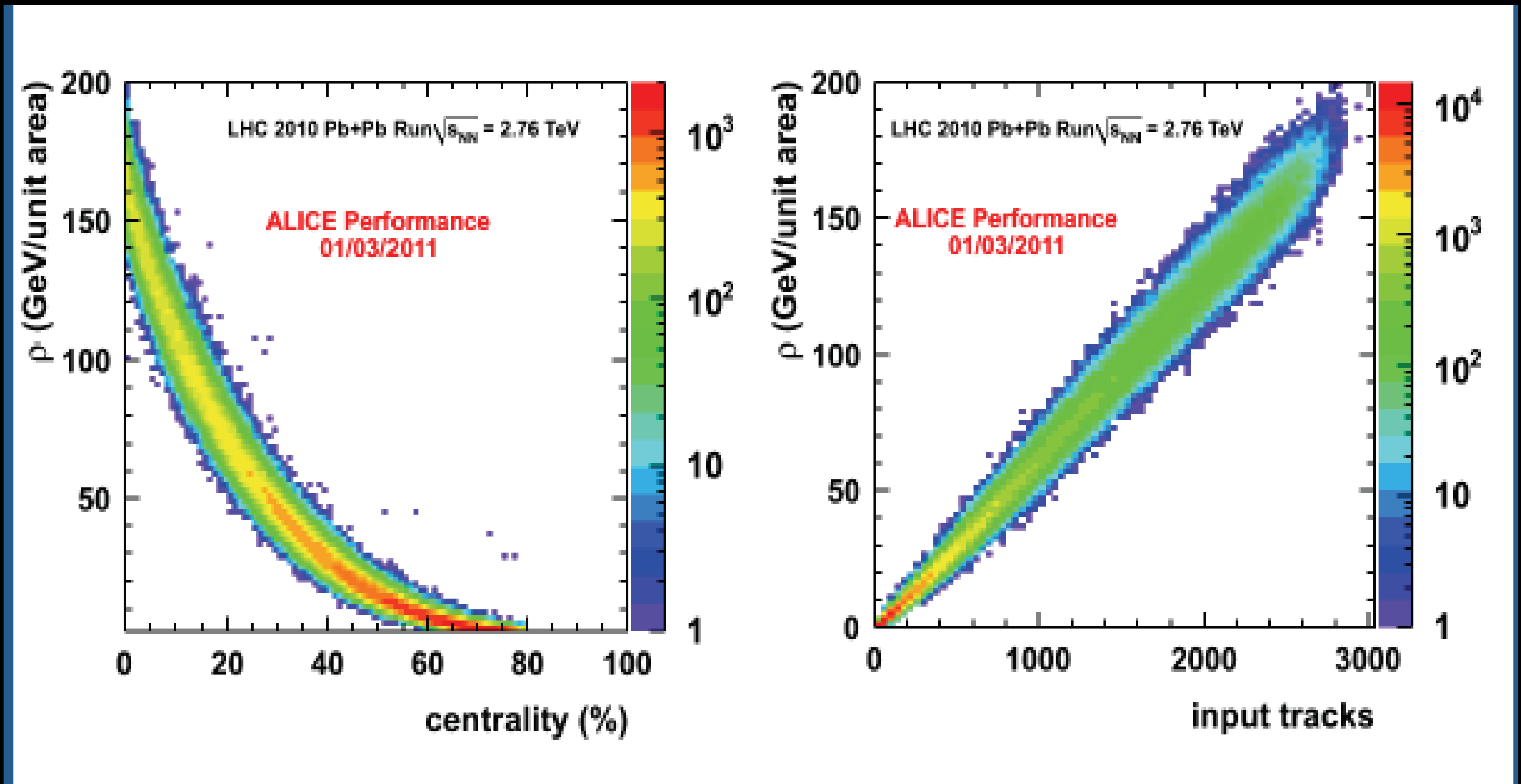
Background coming from the UE contaminates the jet proportionally to its area.

In ALICE we follow a two step procedure to correct for background:

1. **Estimate background density ρ event-by-event**:
   cluster up the event using kT algorithm **and obtain** **ρ=median[pTi/Ai]**,
   where pTi and Ai are the momentum and area of the ith jet in the event.
   In the limit of a dense and homogeneous background, every cluster would have momentum density ρ.

2. **Estimate background fluctuations around ρ:** **background non-uniformities cause jet energy irresolution.**
   Quantify via the embedding of probes in HIC events and correct via unfolding.

Background density

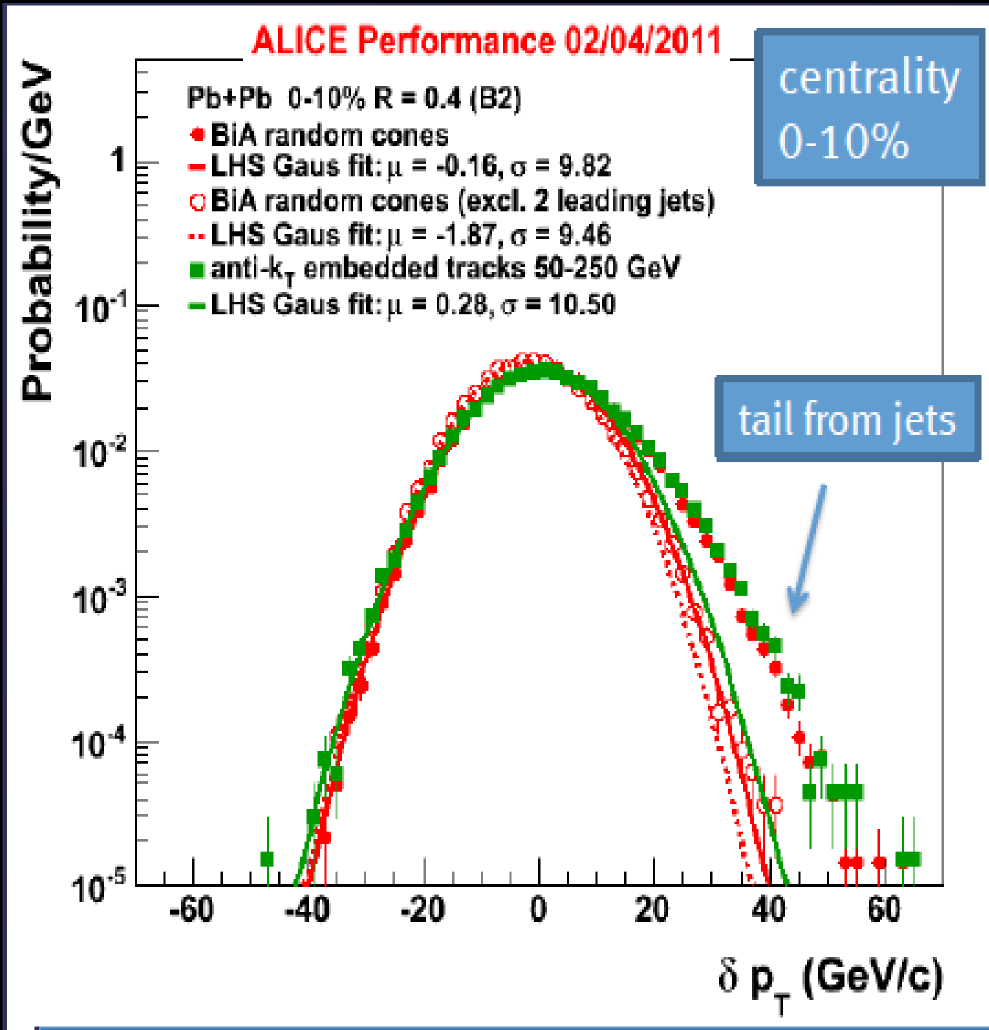


The strong change of ρ with centrality shows multiplicity evolution within centrality bin

Some numbers to keep in mind: In 0-10% central bin, <ρ>≈140 GeV/area

→ an average contamination of 70 GeV in a cone of R=0.4

Background fluctuations



We embed different probes in real HI events:

single tracks: δ probes for background

random cones: fixed area nonoverlapping cones are randomly distributed in the event.

real and simulated quenched/unquenched jets in progres **(rec-gen jet matching is a key issue)**

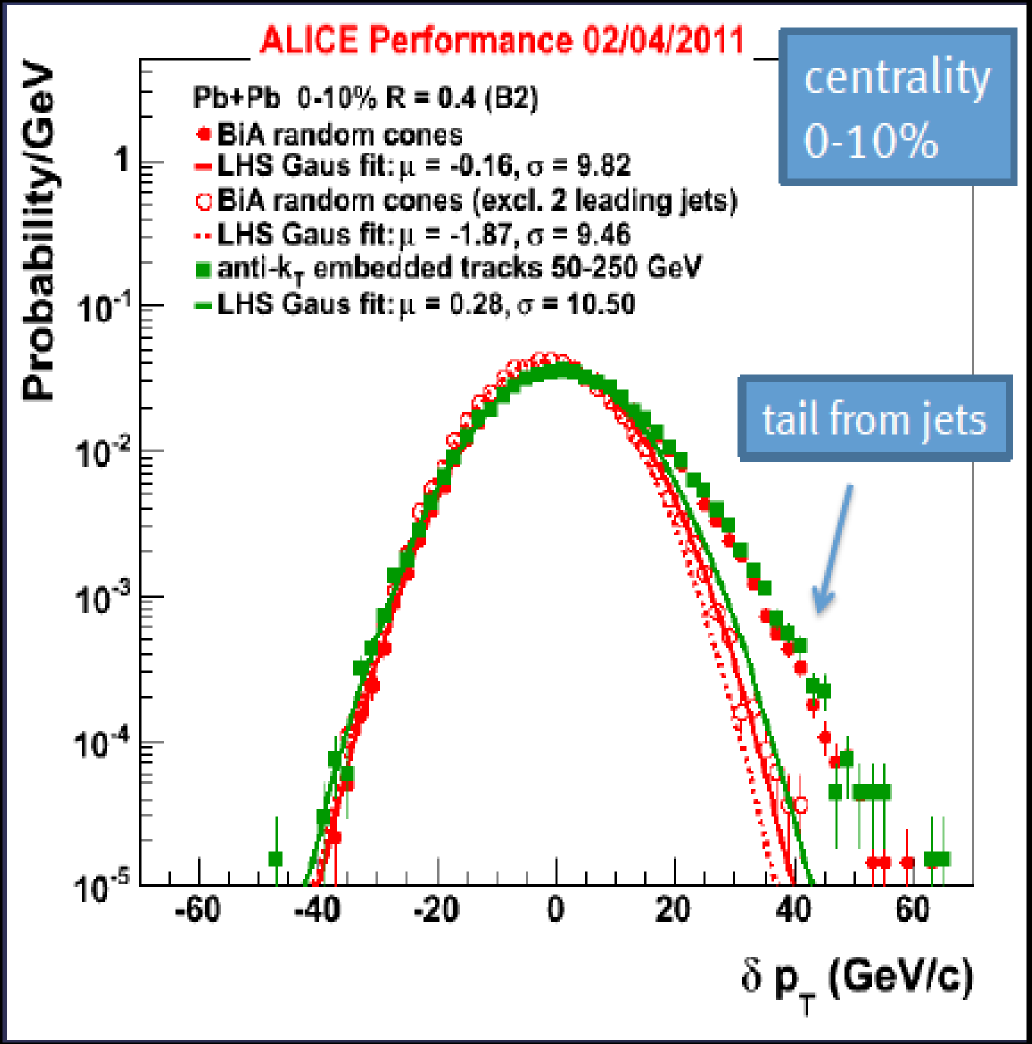
$$\delta pT = p_{T,jet}^{rec} - \rho \times A_{jet} - p_{T,(jet)}^{probe}$$

A_{jet} : jet area

$\rho = \text{median}(p_T / A_{jet})$

$p_{T,jet}^{probe}$: transverse momentum of embedded probe (e.g. jet or single track)

Background fluctuations



Observations:

-Fluctuations seem rather independent on the type of probe.

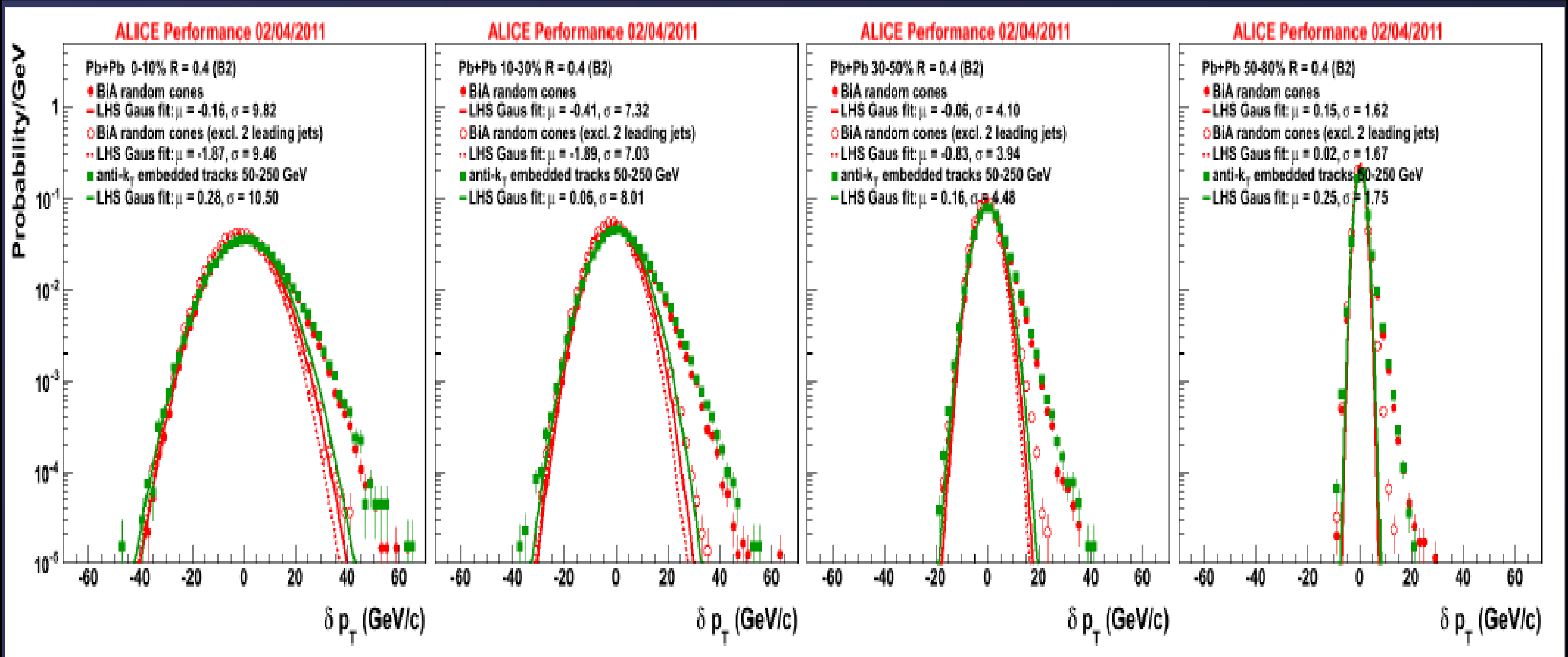
-Background correction should not depend on the fragmentation pattern for it is unknown.

-Fluctuations centered around zero→ check for background subtraction quality.

-High pT tails show presence of the signal.
(See that when the 2 leading random jets are excluded, the tail is suppressed)

→energy irresolution of ~10 GeV in a cone of R=0.4 due to background

Background fluctuations



Fluctuations from LHS fits of δpT distributions show behaviour close to poissonian limit.

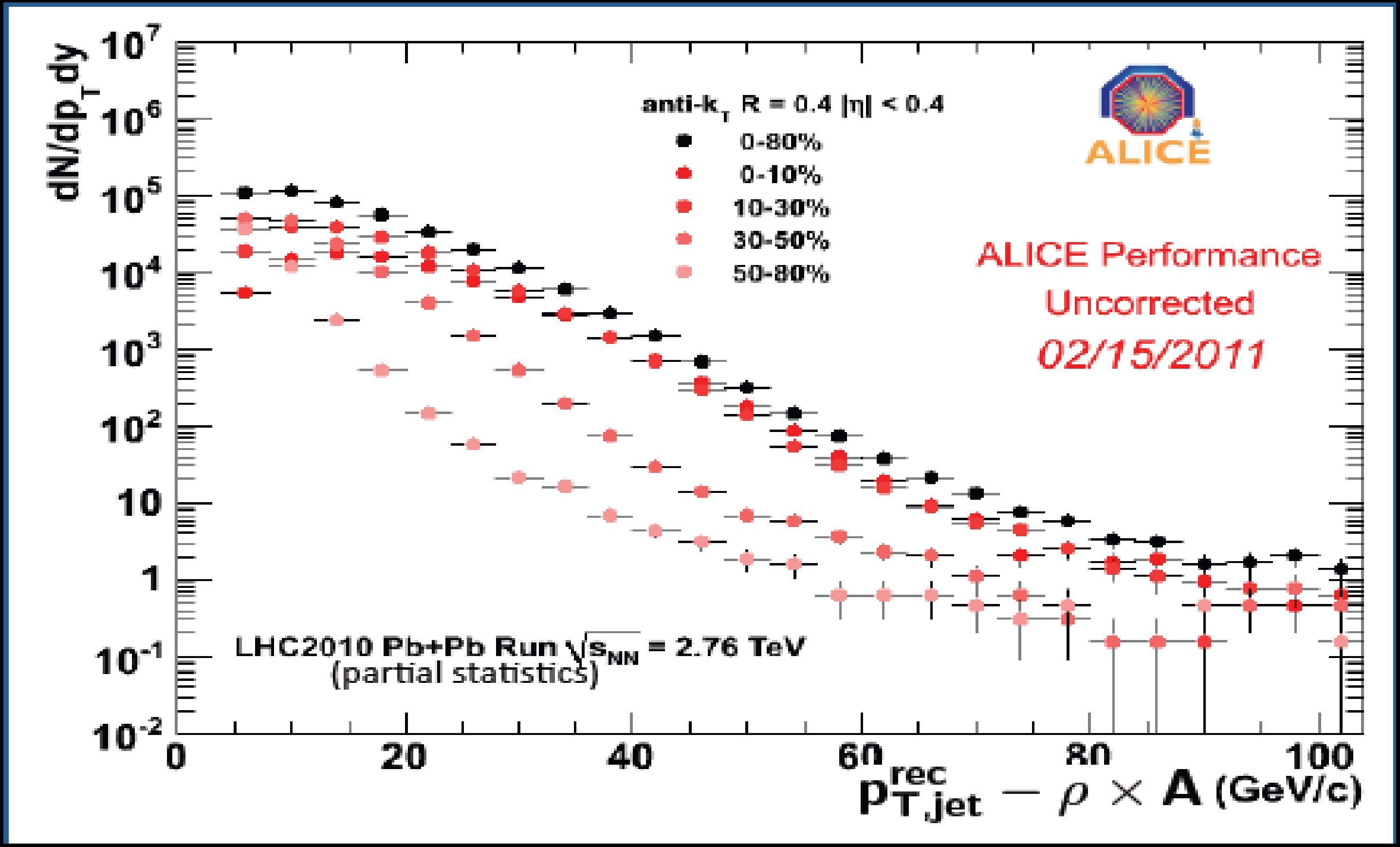
$\sqrt{N} * \sqrt{\langle p_T \rangle^2 + RMS(p_T)^2}$	Ratio to central	Data: $\sigma(\delta p_T)$	Data: ratio to central	Data: $\sigma(\delta p_T)$ (randomized Events)
8.75	1	9.82	1	8.66
6.42	0.73	7.3	0.74	6.87
4.07	0.47	4.1	0.42	4.22
1.96	0.22	1.62	0.16	1.79

Background subtraction quality is independent on the level of background.

central

peripheral

The inclusive cross section



Raw antikT jet spectrum for different centralities.
Background is subtracted on average on an event by event basis.
Smearing of the spectrum due to residual background fluctuations is apparent: correction via unfolding is in progress.

Conclusions

-Current status of the analysis of the inclusive jet spectrum in ALICE was presented

-Emphasis on background corrections: irresolution in the jet energy due to background fluctuations is the largest uncertainty

-Extensive studies on background irresolution in progress:
study dependence on type of probe, on jet area,on fragmentation pattern, angle with respect to reaction plane…

-Physics to come soon: RAA for jets, ratio of the jet cross section for different resolutions, intrajet distributions…..

back up

Jet algorithms

Recombination algorithms are baseds on successive pair-wise recombination of particles:

1. For each pair of particles i, j work out the k_t distance

$$d_{ij} = \min(k_{ti}^{2p}, k_{tj}^{2p})\, \Delta R_{ij}^2 / R^2$$

   with $\Delta R_{ij}^2 = (y_i - y_j)^2 + (\phi_i - \phi_j)^2$, where k_{ti}, y_i and ϕ_i are the transverse momentum, rapidity and azimuth of particle i and R is a jet-radius parameter usually taken of order 1; for each parton i also work out the beam distance $d_{iB} = k_{ti}^{2p}$.

2. Find the minimum $d_{\min}$ of all the d_{ij}, d_{iB}. If $d_{\min}$ is a d_{ij} merge particles i and j into a single particle, summing their four-momenta (this is E-scheme recombination); if it is a d_{iB} then declare particle i to be a final jet and remove it from the list.

3. Repeat from step 1 until no particles are left.

When p=1 we recover k_T while $p = -1$ corresponds to antikT definition. Note that minimization of k_T distance is just a maximization of QCD splitting probability so k_T traces back the QCD branching sequence. This is not the case of antik_T.
Note also that k_T starts clustering the low p_T particles among themselves while the antik_T proceeds by clustering around the hardest first. These different approaches lead to different jet properties: the k_T jet is soft-adaptable, meaning that its area is arbitrarely shaped in η,ϕ. The antik_T jet is soft resilient and its area is smaller and like a pure cone jet area at high p_T [?]. Depending on its area a jet will be differently affected by pileup background ($\propto R^2$), hadronization ($\propto 1/R$) or pQCD radiation($\propto R$).

Centrality determination

- estimate centrality of collision with V0 detector
- V0 detector:
  - two arrays of 32 scintillator tiles
  - $2.8 < |\eta| < 5.1$, $-3.7 < |\eta| < -1.7$

PRL 106, 032301 (2011)
arXiv:1012.1657v2

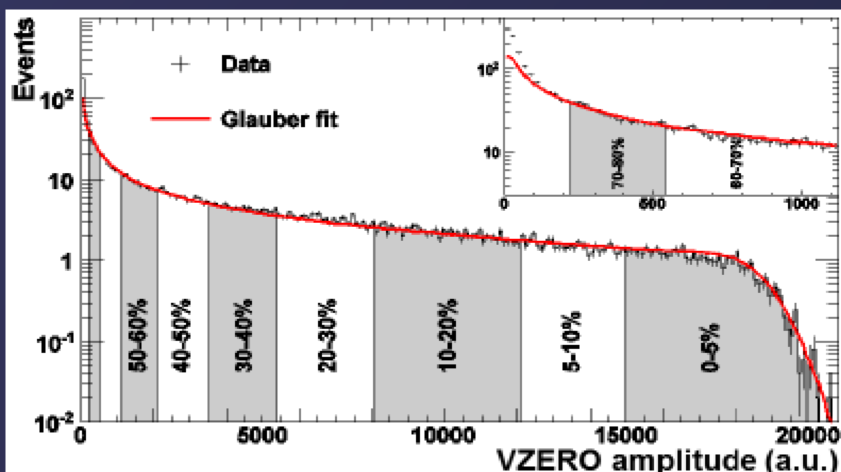
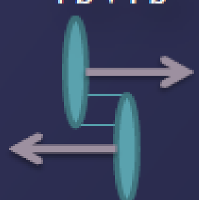


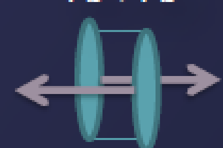
TABLE I. $dN_{ch}/d\eta$ and $(dN_{ch}/d\eta)/(\langle N_{part}\rangle/2)$ values measured in $|\eta| < 0.5$ for nine centrality classes. The $\langle N_{part}\rangle$ obtained with the Glauber model are given.

Centrality	$dN_{ch}/d\eta$	$\langle N_{part}\rangle$	$(dN_{ch}/d\eta)/(\langle N_{part}\rangle/2)$
0%–5%	1601 ± 60	382.8 ± 3.1	8.4 ± 0.3
5%–10%	1294 ± 49	329.7 ± 4.6	7.9 ± 0.3
10%–20%	966 ± 37	260.5 ± 4.4	7.4 ± 0.3
20%–30%	649 ± 23	186.4 ± 3.9	7.0 ± 0.3
30%–40%	426 ± 15	128.9 ± 3.3	6.6 ± 0.3
40%–50%	261 ± 9	85.0 ± 2.6	6.1 ± 0.3
50%–60%	149 ± 6	52.8 ± 2.0	5.7 ± 0.3
60%–70%	76 ± 4	30.0 ± 1.3	5.1 ± 0.3
70%–80%	35 ± 2	15.8 ± 0.6	4.4 ± 0.4

Pb + Pb

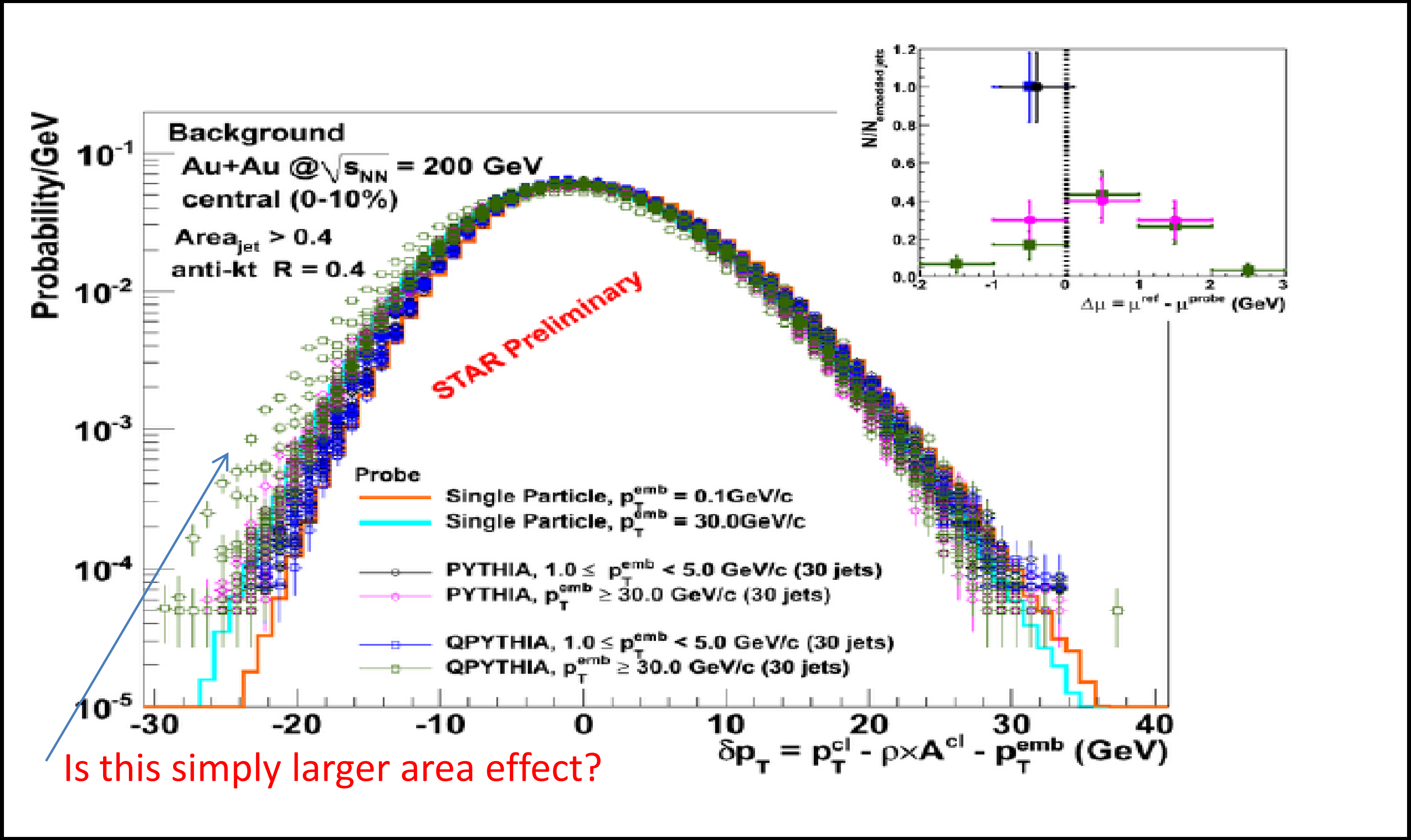


Pb + Pb



peripheral 50-80% ⟷ central 0-10%

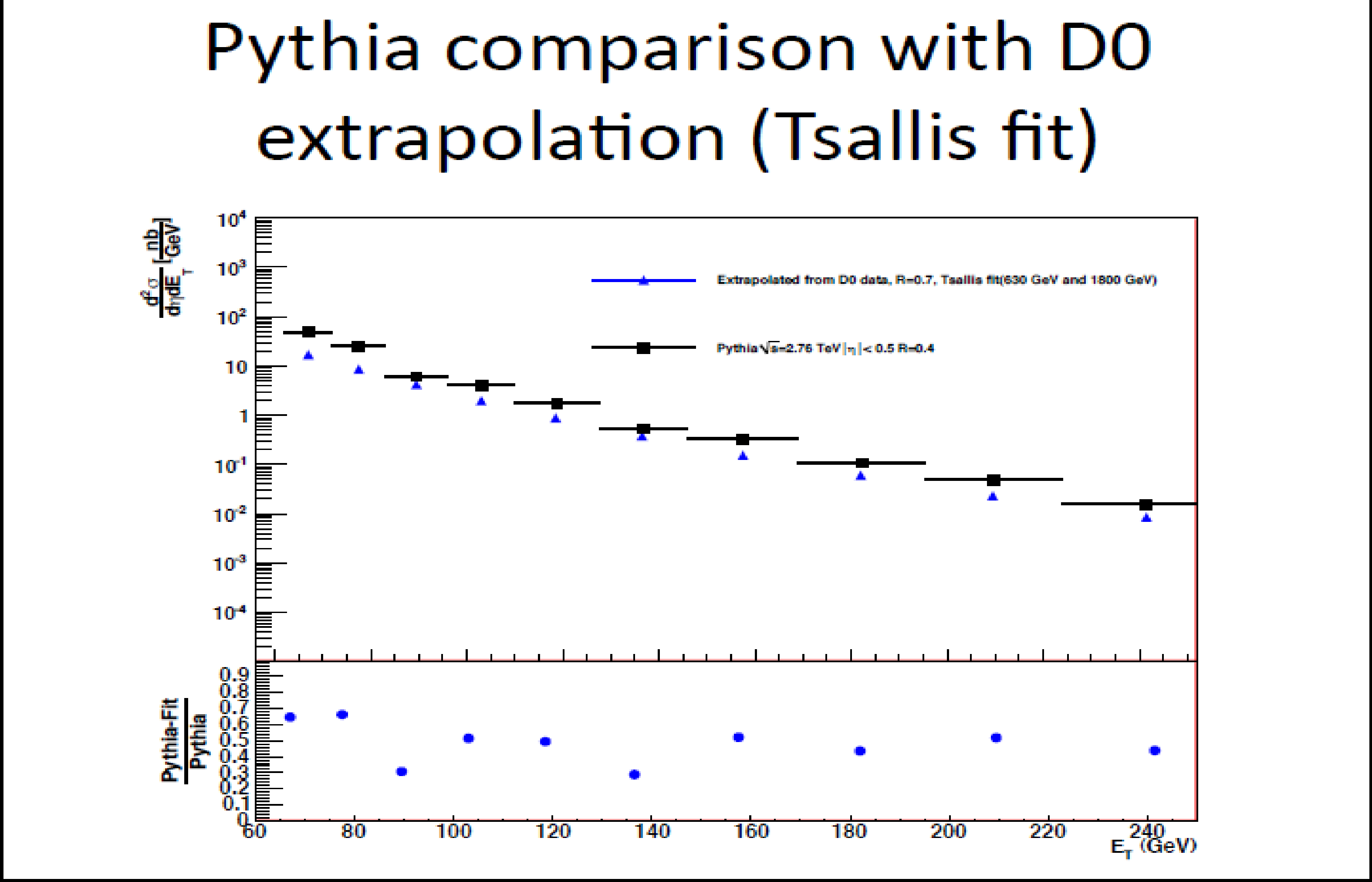
Background&fragmentation pattern



We don't want the background correction to depend on the fragmentation pattern for it is unknown.

Embedding of quenched jets under study in ALICE….

Some shots: RAA/RCP: preparation of a reference spectrum



-Extrapolation of D0 spectra: same acceptance but different resolution R=0.7, including neutrals.

-Extrapolation of Alice pp jet spectrum to 2.76 GeV

-Use peripheral spectrum as reference (low statistics)

Formalisms for energy loss in medium:

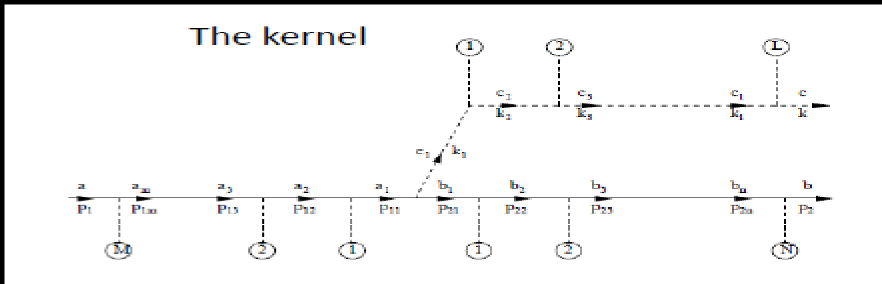
-Mulitple soft scattering (BDMPS-ASW):
- static ensemble of heavy scattering centers
-vacuum and medium intereference is taken into account.
-full LPM interference is considered.

-Hard Thermal Loops (AMY):
-the energy loss is considered in an extended medium in equilibrium at high tempertauteT->∞
-leading order radiation rates are computed (the medium gives kicks of gT) and then multiple emissions are obtained with foker-plank equations.
-weakly coupled plasma
-no interference between vacuum and medium
-flavour changing
-the only one including partonic feedback from the medium.

-Opacity expansion(GLV):
-static yukawa-like scattering centres
-vacuum-medium intereference
-expansion in opacity (default=N=1, single hard scattering)

-Higher Twist (GWM):
-power corrections to the leading twist corss section, which, though suppressed by powers of the hard scale Q2, are enhanced by the length of the medium.
-radiation kernel similar to GLV.
-vacuum radiation in dglap evolution

BDMPS-Z formalism



The medium is modelled as an ensemble of heavy static scattering centers→
→ no recoil, no elastic energy loss
→the medium can be taken as a background field.

The propagation of the incoming-outgoing quark and that of the radiated gluon can be expressed in terms of Green functions:

$$G(\mathbf{x},t_1;\mathbf{y},t_2) = \int \mathcal{D}\mathbf{r}(t)\exp\left\{i\frac{\omega}{2}\int d\xi\left[\frac{d\mathbf{r}(\xi)}{d\xi}\right]^2 + ig\int d\xi A(\mathbf{r}(\xi))\right\}$$

In the **high energy and soft limit (w<<E)** the radiation probability can be derived:

$$\omega\frac{dI}{d\omega} = \frac{\alpha_s C_R}{(2\pi)^2\,\omega^2}\,2\mathrm{Re}\int_{\xi_0}^{\infty} dy_l \int_{y_l}^{\infty} d\bar{y}_l \int d\mathbf{u}\int_0^{\chi\omega} d\mathbf{k}_\perp\, e^{-i\mathbf{k}_\perp\cdot\mathbf{u}}\, e^{-\frac{1}{2}\int_{\bar{y}_l}^{\infty} d\xi\, n(\xi)\,\sigma(\mathbf{u})}$$
$$\times\frac{\partial}{\partial\mathbf{y}}\cdot\frac{\partial}{\partial\mathbf{u}}\int_{\mathbf{y}=0}^{\mathbf{u}=\mathbf{r}(\bar{y}_l)}\mathcal{D}\mathbf{r}\exp\left[i\int_{y_l}^{\bar{y}_l} d\xi\frac{\omega}{2}\left(\dot{\mathbf{r}}^2 - \frac{n(\xi)\sigma(\mathbf{r})}{i\,\omega}\right)\right]. \qquad (2.1)$$

U.A.Wiedemann, Nucl.Phys.B588:303,2000

Medium properties encoded in
n(ζ) =density of scattering centres
σ(r)=dipole cross section, containing information of the strength of the single elastic interaction.

Two approximations to solve eq. 2.1:

1.Mulitple soft scatterings: $n(\xi)\,\sigma(\mathbf{r}) \simeq \frac{1}{2}\,\hat{q}(\xi)\,\mathbf{r}^2$

2.Single hard scattering (derived also by GLV): powers of $(n(\xi)\,\sigma(\mathbf{r}))^N$

Smooth interpolation between the two approaches in 2.1

Multiple soft approximation

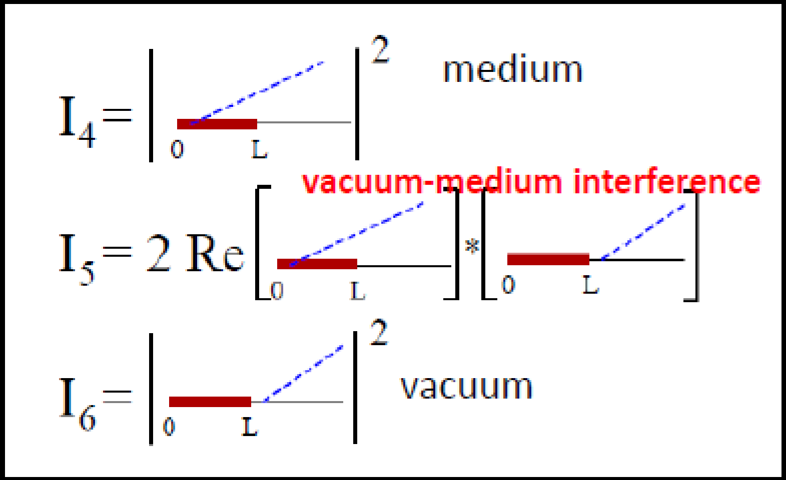
$$\hat{q} = \frac{\langle q_\perp^2 \rangle_{\rm med}}{\lambda}$$

Brownian motion in transverse space

Transport coefficient: average transverse momentum given by the medium to the hard parton per unit path length

In this approximation the path integral in 2.1 simplifies to that of an harmonic oscilator and the medium spectrum can be calculated as:

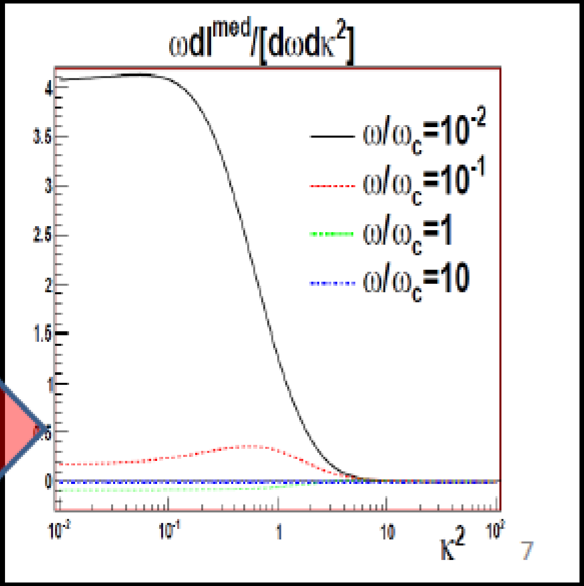
$$\frac{d^3\sigma_{med}^{(nas)}}{d(\ln x)\, dk_\perp} = \frac{\alpha_s}{\pi^2} N_c C_F \, (I_4 + I_5)$$



In a medium of length L the gluon gains enough transverse kicks to decohere from the hard parton at ω~ωc:

$$\varphi = \left\langle \frac{k_\perp^2}{2\omega} \Delta z \right\rangle \sim \frac{\hat{q}\, L}{2\omega} L = \frac{\omega_c}{\omega}$$

coherence



Multiple soft approximation

$$\lim_{R\to\infty} \omega\frac{dI}{d\omega} \simeq \frac{2\alpha_s C_R}{\pi} \begin{cases} \sqrt{\frac{\omega_c}{2\,\omega}} & \text{for} \quad \omega < \omega_c\,, \\ \frac{1}{12}\left(\frac{\omega_c}{\omega}\right)^2 & \text{for} \quad \omega > \omega_c\,. \end{cases}$$

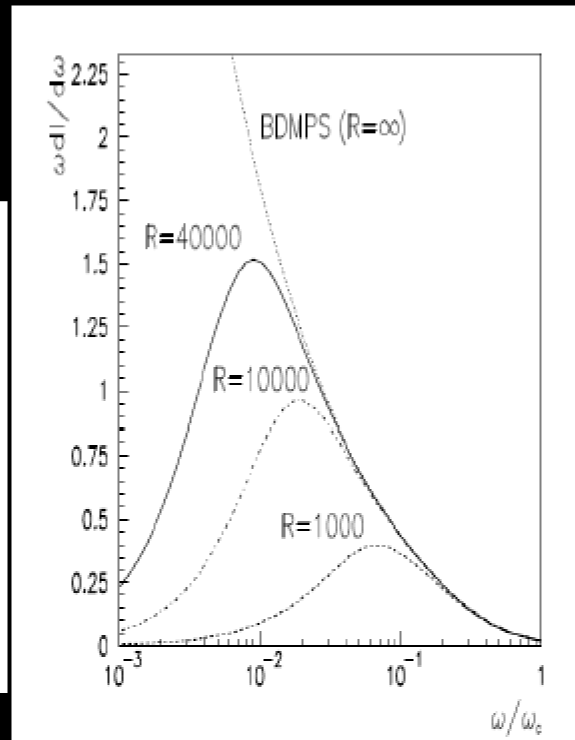
LPM coherence qualitatively:

$$t_{coh} \simeq \frac{\omega}{k_T^2} \simeq \sqrt{\frac{\omega}{\hat{q}}}$$

$$N_{coh} = \frac{t_{coh}}{\lambda}$$

The energy spectrum is suppressed as $\sqrt{\frac{1}{\omega}}$:

$$\omega\frac{dI}{d\omega dz} \simeq \omega\frac{1}{N_{coh}}\frac{dI^{1scatt}}{d\omega dz} \simeq \frac{\alpha_S}{t_{coh}} \simeq \alpha_S\sqrt{\frac{\hat{q}}{\omega}}$$



$$\langle \Delta E \rangle_{R\to\infty} = \lim_{R\to\infty} \int_0^\infty d\omega\,\omega\frac{dI}{d\omega} = \frac{\alpha_s C_R}{2}\,\omega_c$$

→ ΔE~L2